H-8-01 (Invited)

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp535-536

High Performance III-nitride Photodetectors Using Nanoplasmonic Effects

Dabing Li, Xiaojuan Sun, Yuping Jia, Zhiming Shi, You Wu

State Key Laboratory of Luminescence and Applications,
Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences,
3888 Dongnanhu Road
Changchun 130033, China.
Phone: +86-043186176345 E-mail: lidb@ciomp.ac.cn

Abstract

Nanoplasmonic effect is attracting more and more attention for applying in optoelectronic devices to enhance the performance. In 2012, high performance GaN UV detector was realized by Ag nanoparticles plasmonic effect. The responsivity of the GaN detectors with Ag nanoparticles was enhanced more than 30 times compared with that without Ag. Moreover, the responsivity of AlGaN solar blind photodetectors was improved by Al nanoparticles. The mechanism of Surface Plasmon enhancement on the spectral response of the detectors was also investigated. Localized surface plasmon field enhancement was directly observed by Kelvin probe force microscopy (KPFM). This work opens a new way to realize high performance GaN based UV or deep UV detectors.

1. Introduction

Photodetectors (PDs) based on III-nitride have attracted much attention for the small volume, low working voltage, long lifetime, good chemical and thermal stability. Up to now, many efforts have been done on the III-nitride based photodetectors and many kinds of detectors have been fabricated, such as metal-semiconductor-metal (MSM), Schottky, PIN type detectors. However, the performance of the PDs is still far from the expectation. Recent years, nanoplasmonic effect is considered to be an effective way to enhance the performance of photodetectors. When the light is matched with the resonance frequency of surface plasmon, the localized field enhancement or scattering effects will happen and thus the spectral response will be enhanced. The widely used surface plasmon for III-nitride PDs are the nanostructures of gold (Au), silver (Ag) and aluminum (Al) according to different response wavelengths.

2. General Instructions

Ag nanoparticle (NP) is one of the best choices for UV photodetectors due to the low parasitic absorption, high scattering efficiency, and ease of preparation. Our group realized high-performance GaN UV detectors by Ag nanoplasmonic enhancement in 2012.[1] Ag NPs were fabricated by electron beam evaporation (EBE) and then the sample was annealed at 800 °C for 5 min. Fig. 1(a) shows the schematic structure of Ag surface plasmon enhanced GaN-based MSM detectors and Fig. 1(b) shows the spectral response of GaN detectors with and without Ag nanoparticles. The responsivities were approximately 148mA/W and 4000 mA/W at 5 V bias, respectively. Due to the enhancement of surface plasmons, the highest responsivity of GaN UV detectors with annealed Ag NPs has increased more than 30 times. After that, the spectral response of AlGaN solar blind detectors was also improved by Al nanoparticles, whose metal frequency is high and suitable for the deep UV region.[2] The dependence of the surface plasmon resonance frequency on the media around the metal nanoparticles was also investigated in detail.[3]

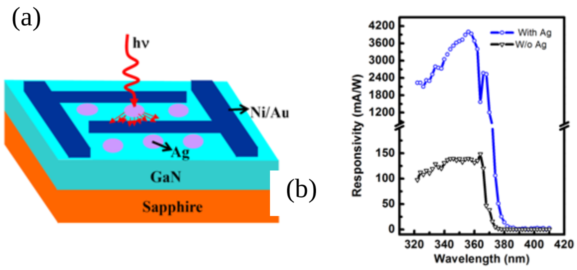

Fig. 1(a) Schematic structure of surface plasmon-enhanced GaN detectors. (b) The responsivity of GaN detectors with and without Ag NPs.

To reveal the physical mechanism, Kelvin probe force microscopy (KPFM) was adopted and the localized field enhancement induced by Surface Plasmon was directly observed.[3] Fig.2 (a) shows the morphology of Ag nanoparticles on GaN surface. Fig.2 (b) shows the cross section of the Ag nanoparticle. Fig.2 (c) and (d) are the surface potential of samples before and after UV light illumination. Fig.2 (e) and (f) exhibit the cross section potential line of single Ag nanoparticles before and after UV light illumination, while Fig.2 (g) and (h) are that of dimer Ag nanoparticles before and after UV light illumination. Under UV light, the localized field enhancement resulted in the photo generated electrons drifting close to the Ag NPs, and thus reducing the surface potential around the Ag NPs. The lowest surface potential between the Ag nanoparticles confirmed the localized surface plasmon effect, as shown in Fig.2 (h).

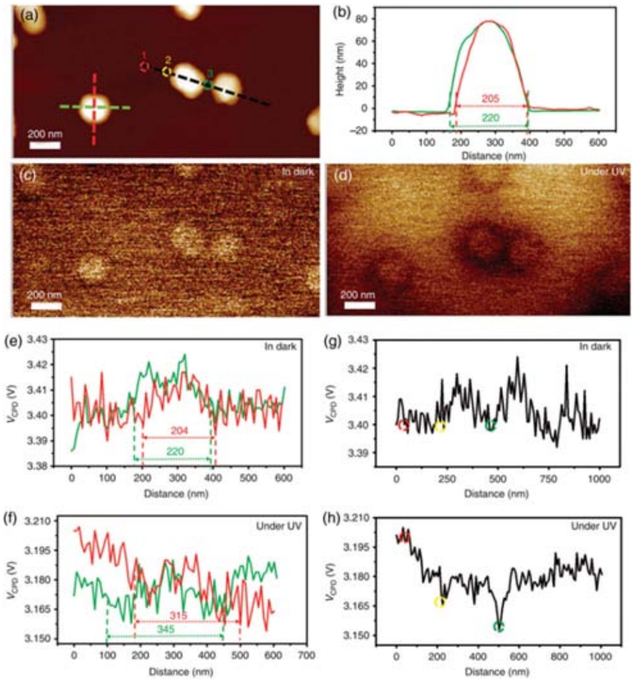

Fig. 2 Surface potential reduction in the vicinity of Ag NPs on a GaN epilayer measured by KPFM.[2]

3. Conclusions

High performance III-nitride photodetectors have been realized by nanoplasmonic effects. The responsivity of GaN detectors was increased more than 30 times by Ag nanoparticles deposition. The performance of AlGaN solar blind detectors was improved by Al nanoparticles. KPFM was adopted to study the mechanism of surface plasmon enhancing the spectral response of III-nitride photodetectors. The change of surface potential around Ag nanoparticles on GaN surface was directly observed, which is associated with localized surface plasmon effect. These work will further deepen the understanding of surface plasmon as well as open a new way to realize weak signals detection in future.

Acknowledgements

This work was supported by the National Key R&D Program of China (2016YFB0400101), National Science Fund for Distinguished Young Scholars (61725403).

References

[1] D. B. Li, X. J. Sun, H. Song et al, Adv. Mater. **24** (2012) 845
[2] G. H. Bao, D. B. Li, X. J. Sun, et al, Opt. Express 22 (2014) 24286
[3] X. T. Liu, D. B. Li, X. J. Sun, et al., Sci. Rep. 5 (2015) 12555.
[4] D. B. Li, X. J. Sun, Y. P. Jia et al, Light-Sci. Appl. **6** (2017) 1